NASA-CR-196808

1. INTRODUCTION

NAGW-1919

Research in particle astrophysics at the Space Radiation Laboratory (SRL) of the California Institute of Technology is supported under NASA Grant NAGW-1919. A three-year proposal for continuation of support was submitted two years ago and put into effect 1 October 1992. This report is the combined progress report and continuation application called for under the Federal Demonstration Project. Gamma-ray Astrophysics at SRL is separately supported under NAGW-1919 and will be separately summarized and proposed.

This report documents progress and plans for our particle spectroscopy activities and for related data analysis, calibration, and community service activities. Also included are a bibliography and a updated budget.

The Caltech SRL research program includes a heavy emphasis on elemental and isotopic spectroscopy of energetic particles in the cosmic radiation; including Galactic cosmic rays, solar energetic and interplanetary particles, "anomalous" cosmic rays, and particles associated with planetary magnetospheres. The principal activities currently supported under this grant are the analysis of data from the IMAX balloon experiment flown in 1992, and the collaborative development of a new Isotope Magnet eXperiment (ISOMAX), scheduled for a first balloon flight in mid-1995.

2. STATUS REVIEW

2.1 Data Analysis from the Isotope Matter/Antimatter eXperiment (IMAX)

The Isotope/Matter/Antimatter eXperiment (IMAX) was developed under this grant to measure the abundances of cosmic ray antiprotons and H and He isotopes from ~0.2 to ~3 GeV/nuc. IMAX was a superconducting magnetic spectrometer made up of the NMSU balloon-borne magnet facility supplemented by TOF, Cherenkov, drift chamber, and scintillation counters to measure particle charge, mass velocity, and rigidity. IMAX was flown in July, 1992 from Lynn Lake, Manitoba, collecting a total of ~18 hours at float and about six hours of ascent data. All counters performed as designed throughout the flight, and more than 3 x 10^6 events were collected.

IMAX data analysis is now proceeding in parallel at the five institutions involved in the collaboration: GSFC, Caltech, NMSU, the University of Siegen, DSRI, and the University of Arizona. Caltech graduate student Allan Labrador is working on IMAX data analysis for his Ph.D. thesis; Research Fellow Andrew Davis is also assisting in the data analysis. We report here mainly on progress that has been made at Caltech over the past year.

2.1.1. Detector Response Algorithms: There are now working response algorithms for all detectors that can be utilized at each of the participating institutions. Caltech has had primary responsibility for the two Aerogel Cherenkov counters (C2 and C3), which have indices of refraction of $n \approx 1.044$, with a threshold energy of ~2 GeV/nuc. Response maps of these counters have now been derived using both pre-flight muon and flight data and a new technique that simultaneously fits the normalized-response and the index of refraction of a given location (see Figure 2.1-1). The counters are uniform to about ±10%; this same analysis has also shown that any non-uniformities in the index of refraction are small. Monte Carlo studies have been conducted to understand the influence of knock-on electrons on the velocity response and the resolution. This work has resulted in working algorithms that can be used to derive the velocity of particles above the Cherenkov threshold. When

(NASA-CR-196808) RESEARCH IN COSMIC GAMMA RAY ASTROPHYSICS: COSMIC RAY PORTION Annual Status Report, period ending 30 Sep. 1994 (California Inst. of Tech.) 21 p

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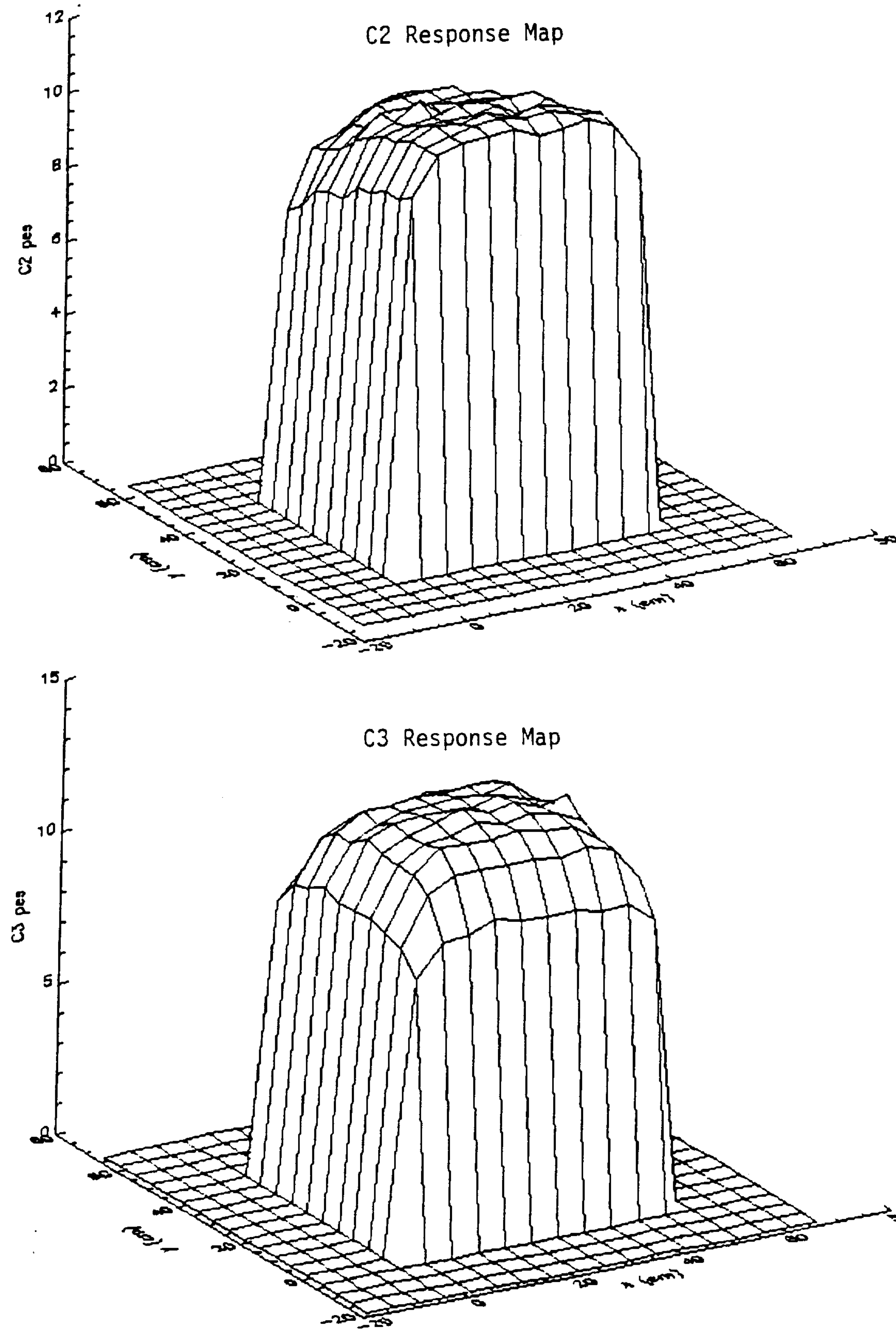

Figure 2.1-1: Response maps of the C2 and C3 Cherenkov counters for IMAX.

combined with rigidity measurements from the drift chambers and proportional counters the C2 and C3 counters provide isotope resolution in the energy range above ~2 GeV/nuc (see below). They are also essential for identifying relativistic electrons and mesons that might form a background for the antiproton analysis.

2.1.2. Light Isotope Abundances: In the energy range from ~0.2 to ~1.7 GeV/nuc IMAX uses the TOF-rigidity approach to resolve cosmic ray isotopes. Figure 2.1-2 shows examples of mass histograms indicating excellent mass resolution of ^{1}H, ^{2}H, ^{3}H (similar resolution is obtained for He isotopes). Work is now underway to understand the instrumental corrections that need to be applied to account for nuclear interactions and data selection criteria. Work has also begun at Caltech to model the production of these rare isotopes in the atmosphere and the Galaxy.

At energies >2 GeV/nuc IMAX uses the Cherenkov-rigidity approach to resolve isotopes, using the C2 and C3 aerogel counters. Figure 2.1-3 shows a mass histogram of He isotopes with 2.6 to 3.2 GeV/nuc, the highest energy to date at which direct cosmic ray isotope measurements have been made. It is clear that IMAX should provide the best study to date of the abundances of H and He isotopes in cosmic rays, providing a good test of whether H and He have the same origin/history as heavier cosmic rays. A preliminary report of this work was presented at the Washington APS meeting in April.

2.1.3. Cosmic Ray Antiprotons: The analysis of the antiproton data from IMAX has been proceeding in parallel at the collaborating institutions. An advantage of the IMAX experimental approach is that it is able to measure not only the rigidity of cosmic ray antiprotons, but also their mass to an accuracy sufficient to separate them cleanly from electrons, muons, pions, and kaons. Figure 2.1-4 shows a plot of TOF velocity vs. mass for flight data with a charge of Q=1. On the right ride of the plot one can see ^{1}H, ^{2}H, and ^{3}H, along with a small response due to positive mesons and electrons. On the left side of the plot there are negative mesons and six cleanly resolved antiprotons. This plot covers only the TOF energy range.

2.1.4. Cosmic Ray Propagation and Atmospheric Secondaries: In preparation for analyzing the isotope data from IMAX, Andrew Davis has been updating our cosmic ray propagation and atmospheric secondary models to include H and He isotopes, using the latest cross sections from our NMSU collaborators.

2.2 The Isotope Magnet eXperiment (ISOMAX)

The Isotope Magnet eXperiment (ISOMAX) is a new superconducting magnet spectrometer under development to measure the isotopic composition of high energy cosmic rays with $2 \leq Z \leq 8$, including an extension of measurements of the important cosmic ray clock ^{10}Be to high energies. A schematic illustration of ISOMAX is shown in Figure 2.2-1. In its first flight ISOMAX will use the TOF-rigidity and Cherenkov-rigidity techniques to resolve cosmic ray isotopes from ~0.2 to ~1.6 GeV/nuc. The experiment is a collaborative effort involving Caltech, GSFC, the University of Siegen, and DSRI.

The dual-coil superconducting magnet system has been ordered by GSFC and is scheduled for delivery in February, 1995. The magnet system is the pacing item in the schedule for a 1995 flight. Caltech has responsibility for a variety of hardware items, including the aerogel Cherenkov counters and their electronics, the Kevlar pressure vessels, the data recording system, the power system, the GPS and gas make-up systems, as well as thermal design and aspects

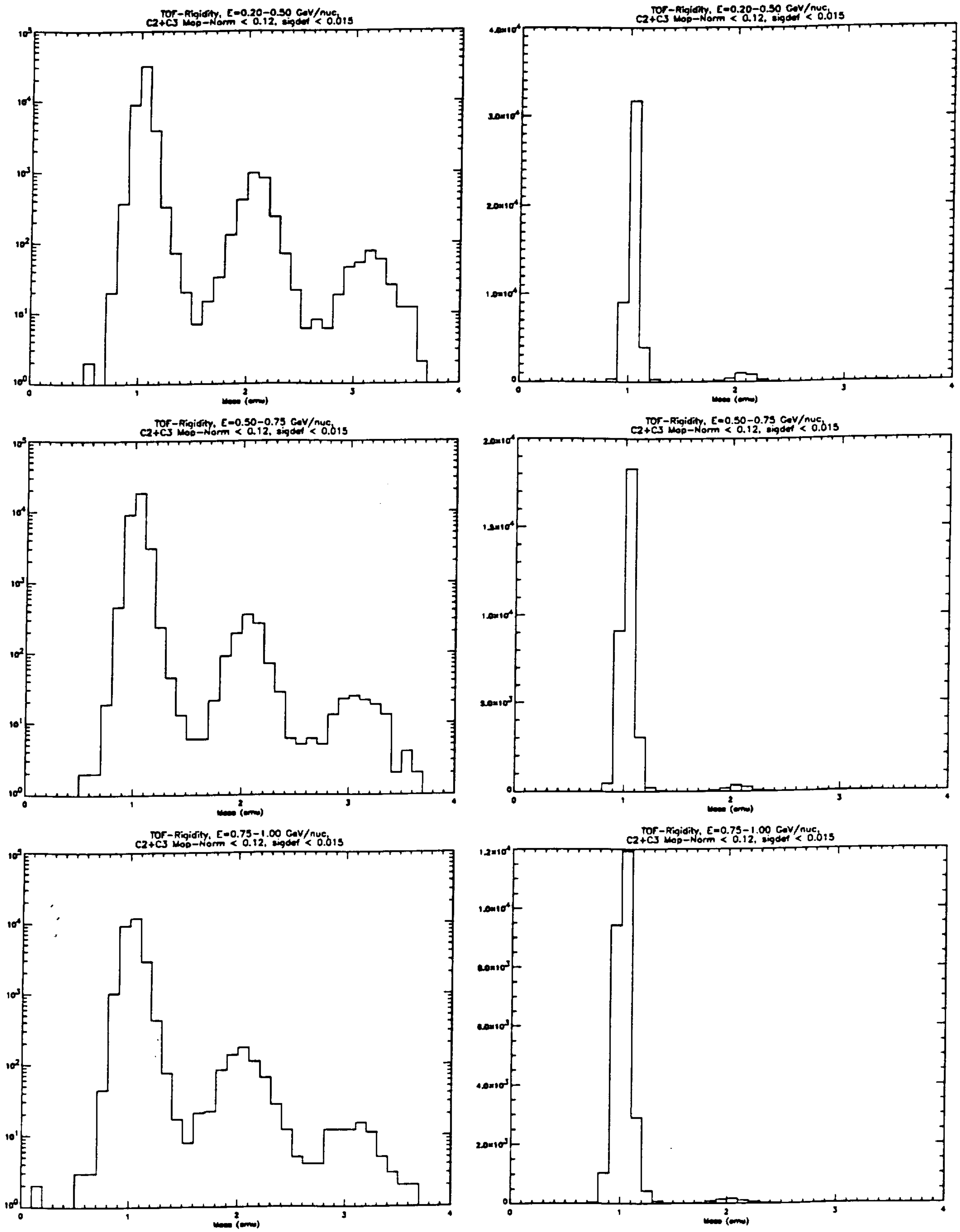

Figure 2.1-2: Mass histograms of H isotopes derived from the time-of-flight vs. rigidity approach in IMAX.

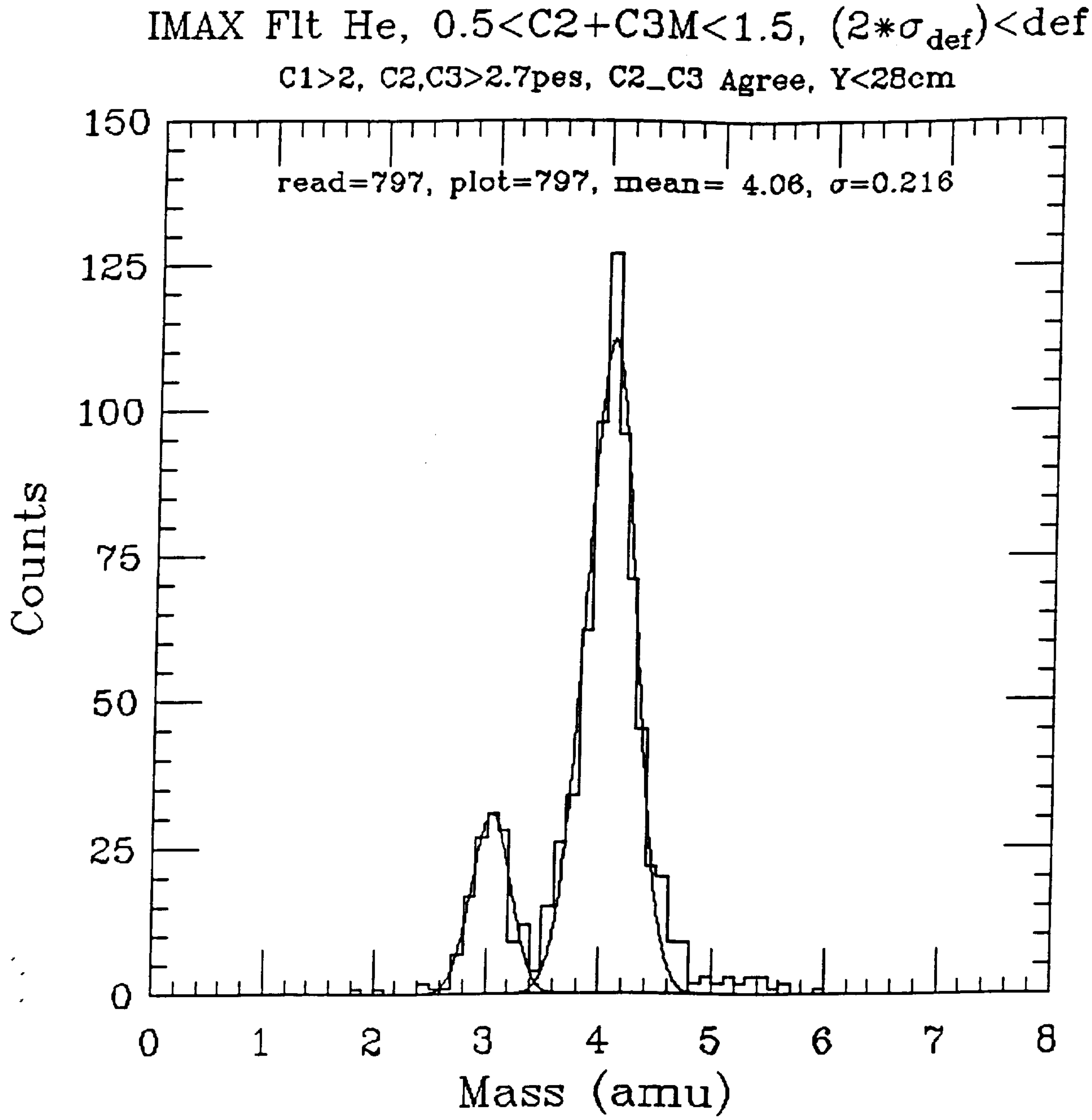

Figure 2.1-3: Mass histogram of 2.6 to 3.2 GeV/nuc He isotopes using the Cherenkov-rigidity approach.

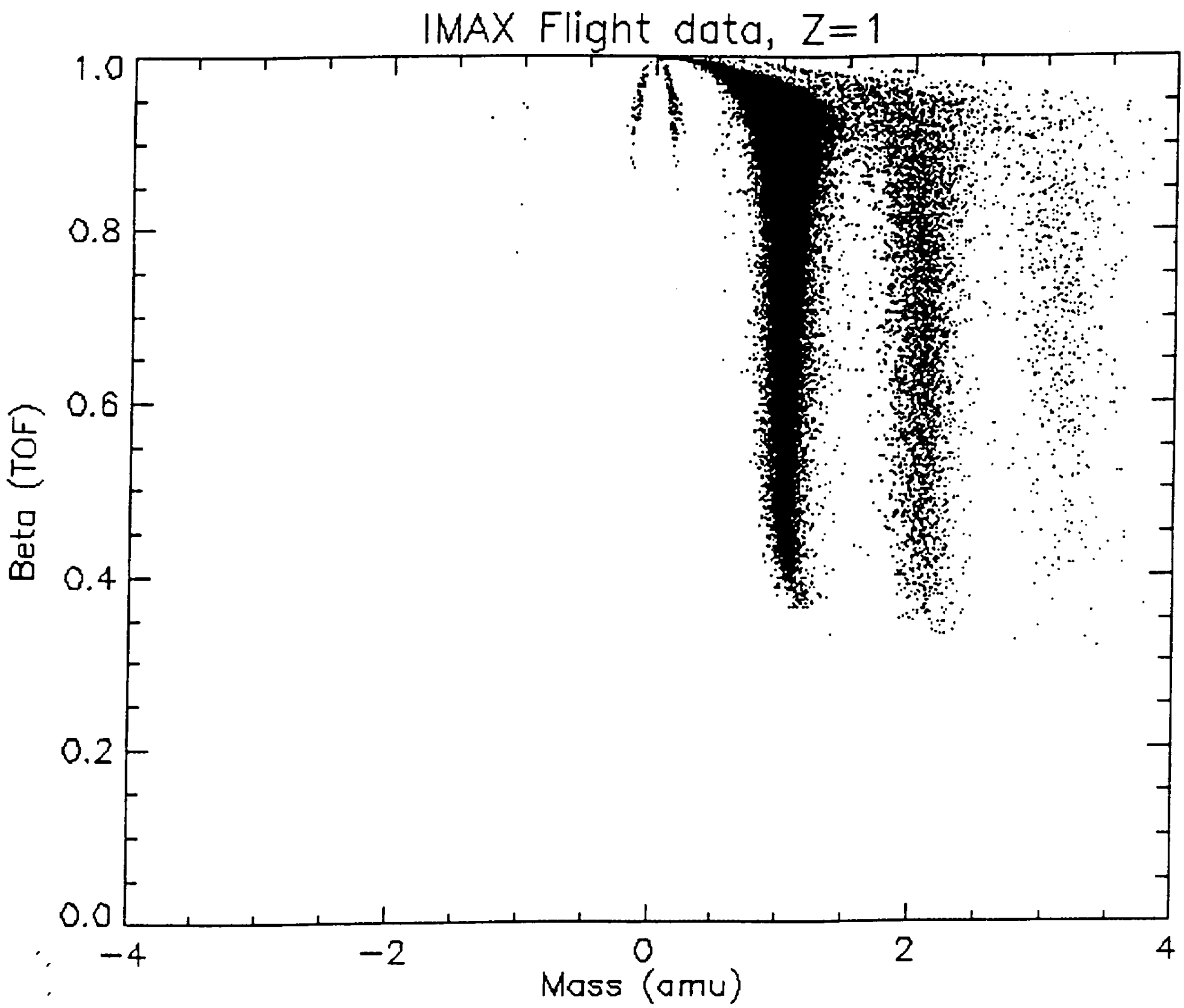

Figure 2.1-4: Time-of-flight vs. mass for singly-charged particles detected by IMAX. Note the six antiprotons.

of the mechanical design. We report here on the status of the various Caltech activities.

2.2.1. Cerenkov Counter Design & Fabrication: During the past year a tradeoff study of the Cherenkov counter design was conducted. The original design had a single counter with an ~8 cm thick radiator viewed by 24 PMTs, with six PMTs on each side. A concern was that the tubes parallel to the axis of the magnet coils required a great deal of additional magnetic shielding, thereby costing considerable mass. It was decided that a better design was to fly two separate counters, each with a 4 cm thick radiator, and each viewed by tubes on only two sides of the counter. This design achieves a somewhat greater light level, and in addition it provides measurement redundancy for identifying and eliminating background. The current design, shown in Figure 2.2-2, will accommodate a total of up to eight tubes on each of two sides of each counter. These counters are now under construction, and should be ready for mounting of the PMTs and Millipore linings within approximately 1 month. The PMTs are currently being tested by a Caltech undergraduate. It is expected that the completed counters will give a total of ~16 to 20 photoelectrons from relativistic muons. A built-in calibration unit will monitor the stability of the counters throughout the flight. Figure 2.2-3 shows a Monte Carlo simulation of the expected mass resolution in the Cherenkov energy range.

2.2.2. Aerogel Radiators: For our first flight we are planning to fly radiators with an index of n=1.15, corresponding to a threshold of ~1 GeV/nuc. Radiators with this index are obtained by "sintering" lower index radiators (heating them to >1000 deg C for ~24 hours). In the sintering process the aerogel contracts to a higher density, with a higher index of refraction. Our colleague, Ib Rasmussen of DSRI, has produced radiators with n=1.15 some years ago with somewhat smaller area, that we tested at the Bevalac in ~1987. Dr. Rasmussen is now developing procedures for sintering n =1.055 blocks that are ~55 x 55 cm^2 in area, which will result in radiators that are about 40 x 40 cm^2 with an index of n=1.15. Four blocks would then be combined in a frame to obtain each of the ~80 x 80 cm^2 layers. Tests have been successful with smaller sizes, and a new shipment of 55 x 55 cm^2 blocks has recently been ordered. The final flight radiators are not needed until the spring of 1995, because the counters can be tested in the meantime with stand-in radiators made of Lucite.

2.2.2. Kevlar Pressure Vessel: Caltech is responsible for procuring a new, light-weight pressure vessel for IMAX, to be made of Kevlar (see Figure 2.2-4). A contract has been awarded to Irvin Industries for the fabrication of three Kevlar pressure vessels. A detailed finite element analysis has verified the basic design, and test samples of the Kevlar material are now being fabricated by Irvin for verification testing of the base material, seam design, and seam sewing technique. Work is proceeding at Caltech on the fabrication of the aluminum attachment rings and the pressure vessel test fixture. Delivery of the first hemisphere is scheduled for November.

2.2.3. Data Recording System (DRS): The DRS for ISOMAX has been up and running for several months and currently consists of two Exabyte SCSI tape drives, controlled by a PC-compatible single board computer (Ampro 386SX). The tape drives under consideration consist of a 5 Gigabyte 8mm model 8505 and a 2 Gigabyte 4mm model 4200. After further testing one of these will be selected for flight. Data can be acquired through a serial port at 57600 bps, or through a custom telemetry I/O board. Testing of the system continues -- several error-free 2-day-long write tests have already been successfully performed. Remaining are temperature tests and integration with the telemetry I/O board.

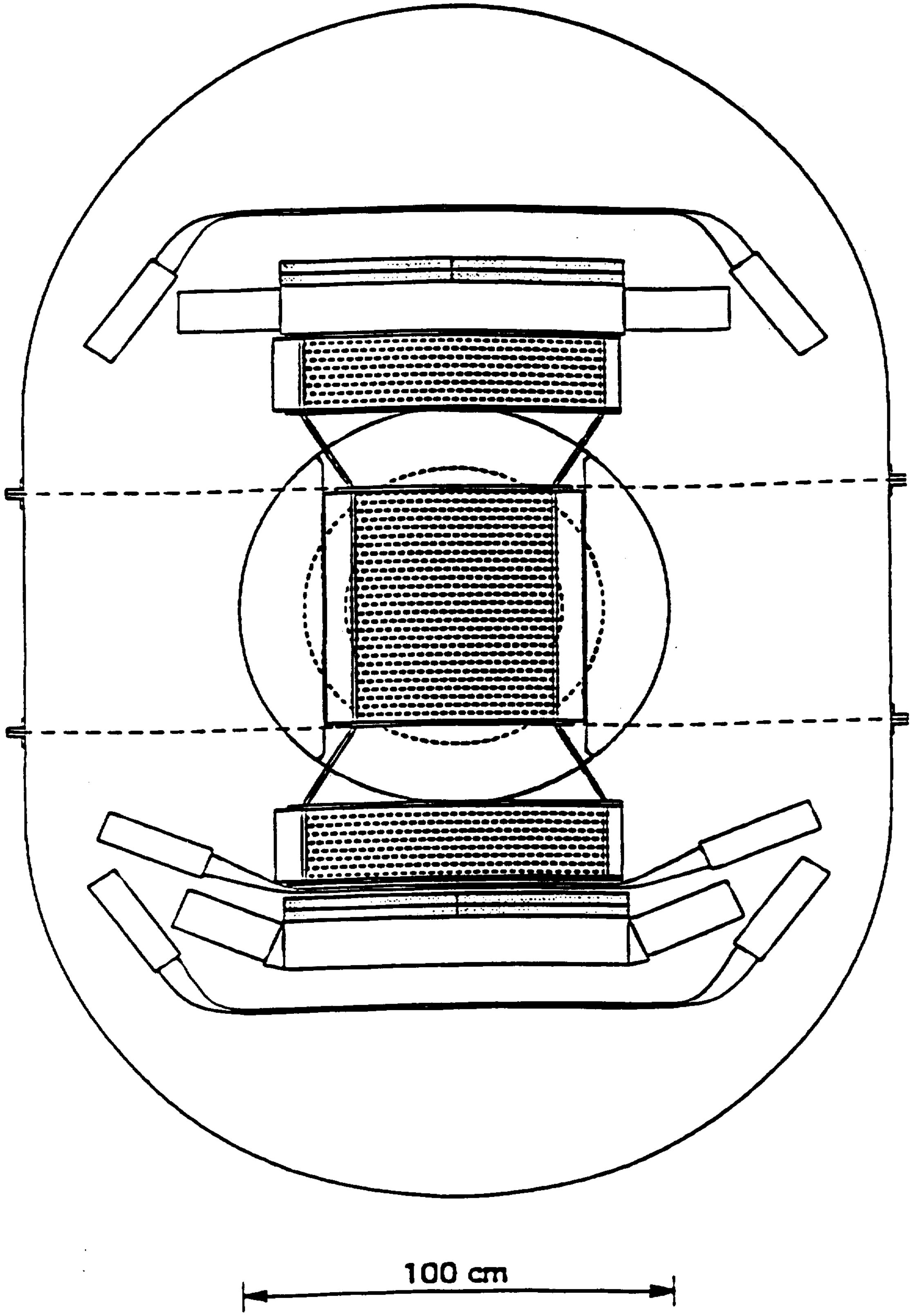

Figure 2.2-1: Schematic illustration of the ISOMAX instrument.

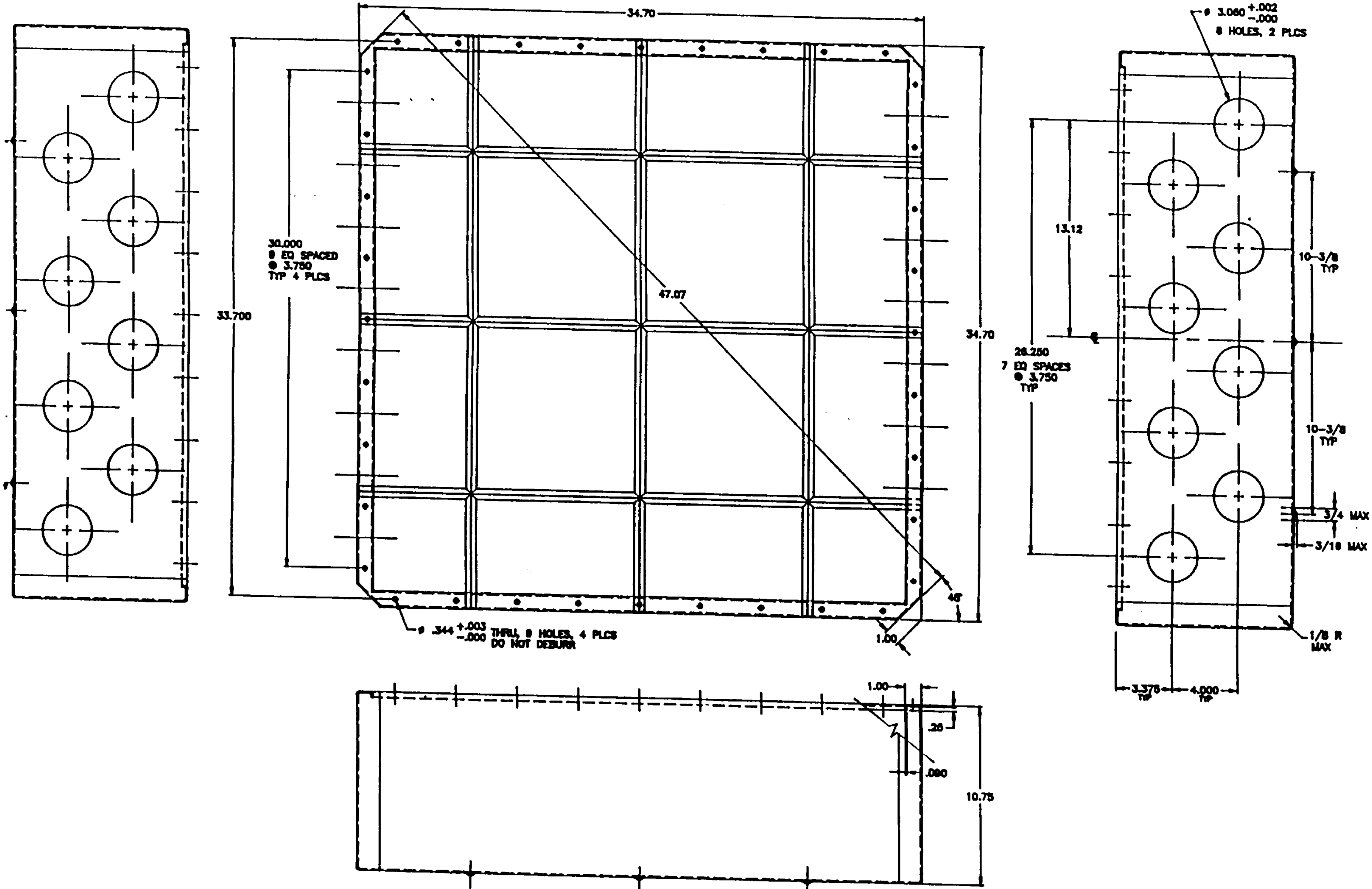

Figure 2.2-2: Engineering drawing of the C1 and C2 Cherenkov counter boxes for ISOMAX.

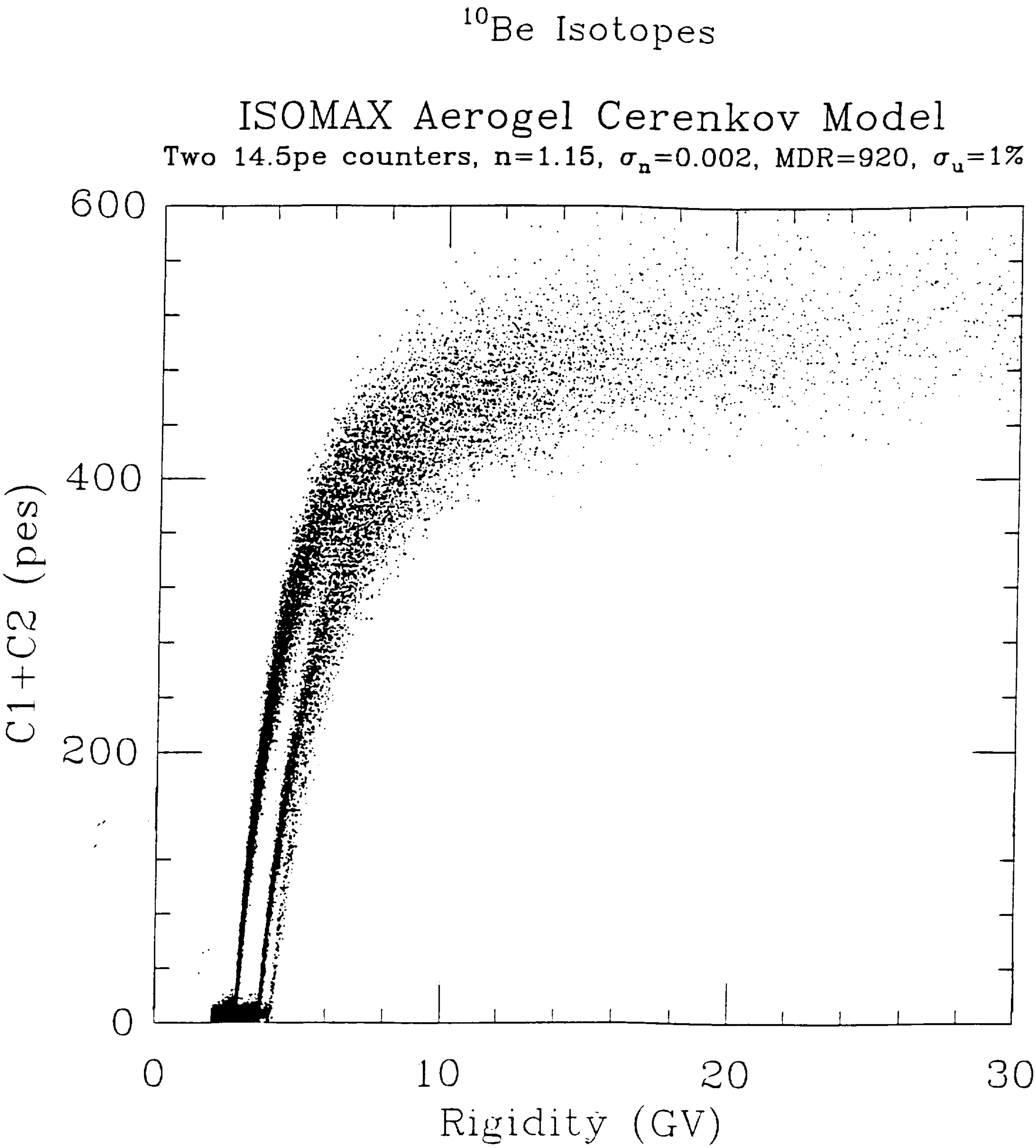

Figure 2.2-3: Monte Carlo simulation of the expected response of ISOMAX to >1 GeV/nuc Be isotopes using the Cherenkov-rigidity approach.

2.2.4. Custom VLSI Electronics: SRL is currently developing custom low-power VLSI pulse-height-analysis chains for the ACE mission. We will be drawing on this experience to develop low-power ADC chains for use in the ISOMAX Cherenkov counters and other long-duration balloon experiments. The ACE development is proceeding as planned, and working prototype circuits are now under test. However, the development schedule of these circuits for ACE has slipped somewhat, such that this work will not be completed in time for the first ISOMAX flight. This is not a problem - on the first ISOMAX flight there is sufficient power to fly Camac modules such as were used in IMAX. Adaptation of the VLSI circuits to ISOMAX will proceed once the ACE development is completed, in time for a long-duration flight when power resources are more critical.

2.2.5 Other Systems: The in-flight GPS system has been purchased and successfully tested. The main ground-based power supply has been purchased and work is now proceeding on the flight power system.

2.2.6. Schedule: The first flight of ISOMAX is scheduled for the summer of 1995 from northern Canada. A two-day flight will provide several hundred ^{10}Be nuclei from ~0.2 to ~1.6 GeV/nuc, as well as other species. This flight will also serve to qualify ISOMAX for a planned long-duration balloon flight from Antarctica in late 1996, which would obtain ~5 times the yield, and extend ^{10}Be measurements to even higher energies. Key milestones in the development schedule are shown below.

9/94: Completion of the C1 and C2 Cerenkov counters
11/94: Proof-pressure test of first gondola shell
11/94: Begin Integration of detector subsystems at GSFC
2/95: Delivery/testing of superconducting magnet at GSFC
3/95: Integration/testing of full instrument
6/95: Ship to Canada
7/95: Balloon Flight

2.3 Interstellar Probe Studies

Just over a year ago one of us (RAM) was invited by Dr. Charles Elachi of JPL to participate in a low-cost study of a Small Interstellar Probe mission. Also participating were S. Kerridge, J. Kangas, and M. Neugebauer of JPL. The study considered spacecraft in the range from ~50 to 200 kg that would make use of small spacecraft technology currently under consideration for the Pluto-flyby and Solar Probe missions, and it considered a variety of trajectory and launch vehicle options. Caltech's role was to define the scientific requirements for the mission, and to survey the community for instrument concepts that could accomplish the primary scientific goals of the mission within limited payload resources.

New trajectory studies for the smaller spacecraft considered here achieved considerably better performance than earlier studies with larger spacecraft, including cruise velocities of up to 8 AU/yr with a Jupiter flyby, and up to ~15 AU/year if a powered solar flyby is employed (see Figure 2.3-1). It was decided that a scientific payload requiring 20-25 kg and ~20 W would best meet the objectives within mission constraints, and a strawman payload was identified. This work was reported in an invited talk and paper at the IAA conference on Low-Cost Planetary Missions held at JHU/APL in April 1994 and in a poster paper at the UNH Outer Heliosphere Conference in June.

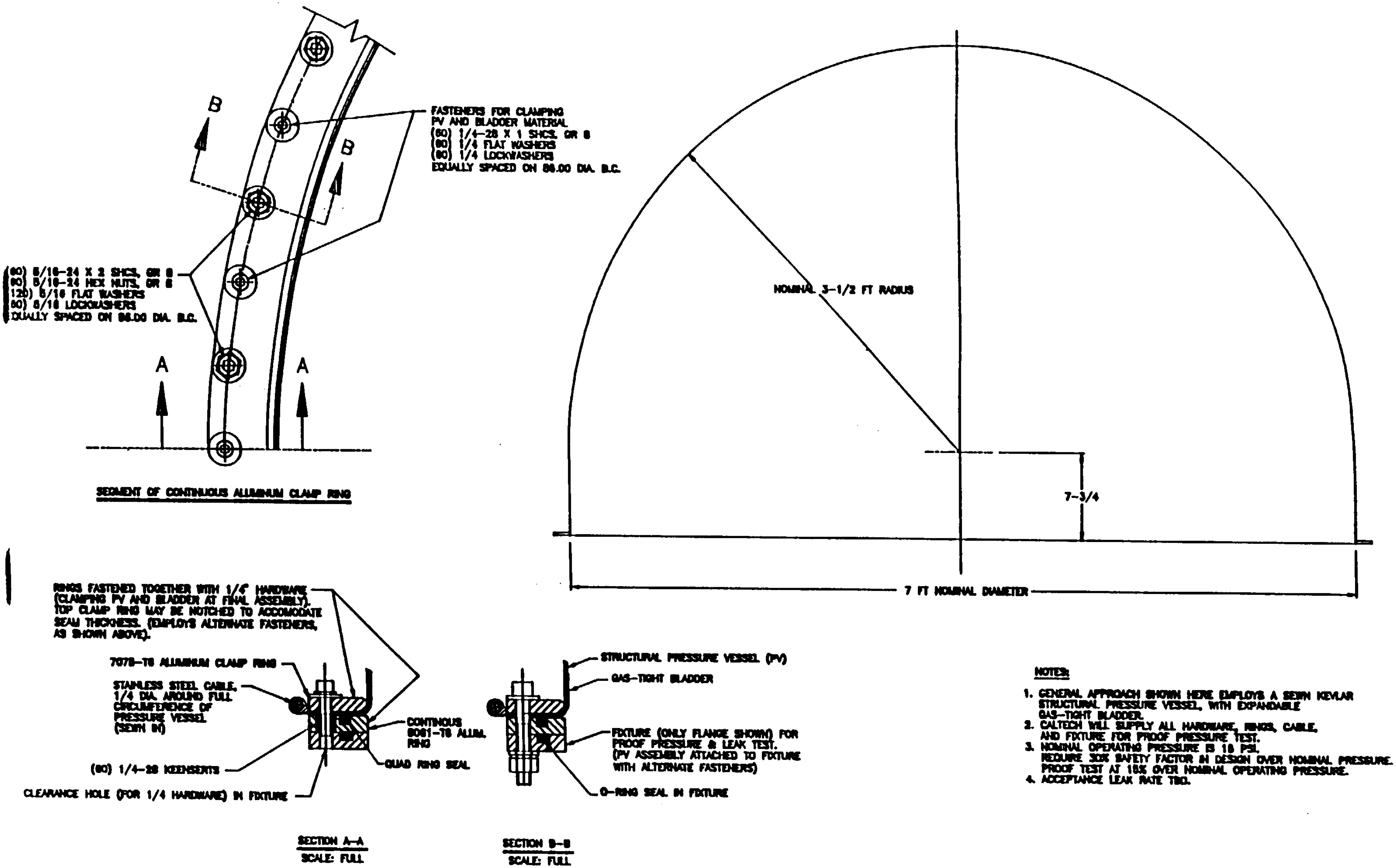

Figure 2.2-4: Drawing of the Kevlar pressure vessel.

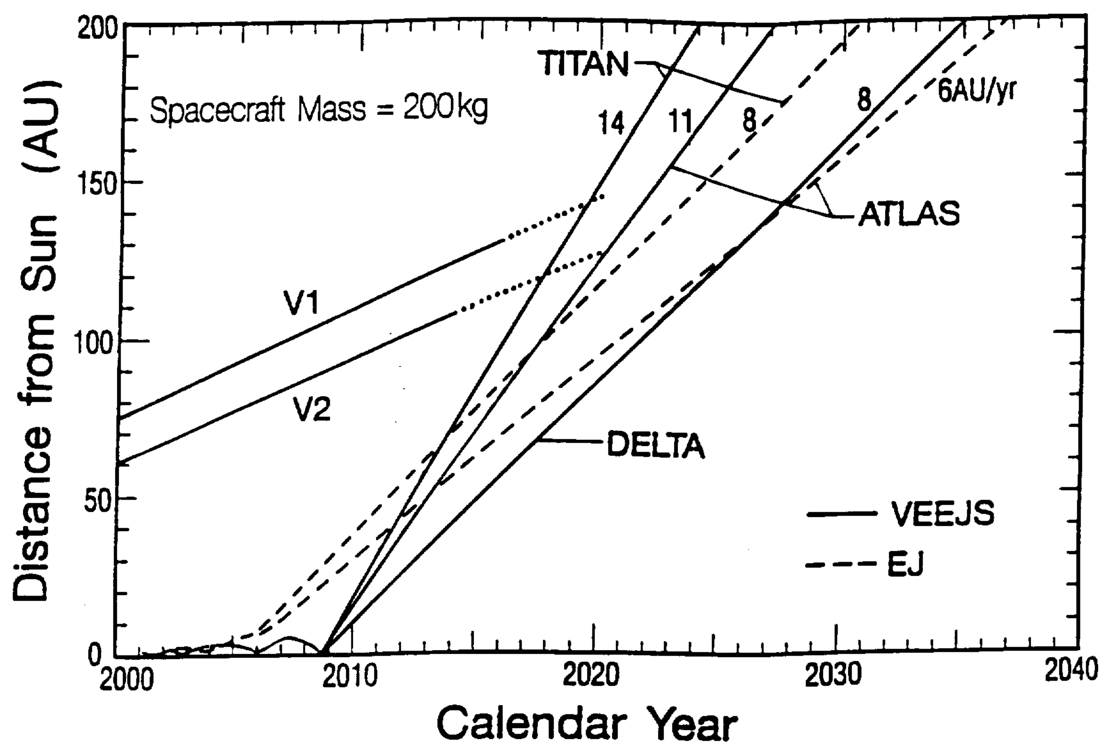

Figure 2.3-1: Illustration of possible Interstellar Probe Trajectories for a 200 kg spacecraft.

2.4. Experiments on Existing NASA Spacecraft

2.4.1. An Electron/Isotope Spectrometer (EIS) launched on IMP-8 in 1973.

This experiment measures the energy spectra of electrons and positrons (0.16 to ~6 MeV) and the differential energy spectra of H, He and other light isotopes from ~2 to ~50 MeV/nuc. Anomalous cosmic ray N and O are measured from ~5 to ~28 MeV/nuc. These measurements support studies of the origin, propagation, and solar modulation of galactic and anomalous cosmic rays; the acceleration and transport of solar energetic particles and of interplanetary particles, and the origin of magnetospheric electrons and ions. On day 216 of 1992 the IMP-8 EIS suffered a partial failure that removes its ability to measure electrons and nuclei with Z>2. Measurements of low energy H and He fluxes continue.

During the past two years we extended our study of anomalous cosmic ray oxygen into the approaching solar minimum, where it overlaps with data from our MAST experiment on SAMPEX. Our IMP-8 experiment was the first to report the return of ACR oxygen in 1992. Based on a study of anomalous cosmic rays observed by IMP over the past two solar cycles we find that the 1992-1993 flux is ~5 times greater than at similar neutron monitor levels in 1971 and 1985. This work was reported in Geophysical Research Letters and at several conferences.

2.4.2. An Interstellar Cosmic Ray and Planetary Magnetospheres Experiment (CRS) for the Voyager Missions Launched in 1977.

This experiment is conducted by members of SRL in collaboration with investigators at GSFC, the University of Maryland, New Mexico State University, and the University of Arizona. It is designed to measure the energy spectra, elemental and isotopic composition, and streaming patterns of cosmic ray nuclei from H to Ni over the energy range from ~1 to ~500 MeV/nuc, and the energy spectra of electrons from ~3 to ~100 MeV.

Over the past year the primary focus has been on using the measured interplanetary gradients and energy spectra of anomalous cosmic ray (ACR) helium and oxygen to detect remotely the location of the solar wind termination shock. The latest results (illustrated in Figure 2.4-1) place the termination shock at ~76 AU in 1993, a distance that will be reached by Voyager 1 before the end of the century.

A new study makes use of measurements from a total of five spacecraft (Voyager 1&2, Pioneer-10, Ulysses, and SAMPEX) to map the three-dimensional distribution of ACR oxygen in the heliosphere. The first results show a small, but positive latitude gradient in 1993, reversed in sign from the last solar minimum as predicted by models that include the effects of drifts in the large scale magnetic field. This study is now being extended to include the periods when Ulysses is making its south and north polar passes.

2.4.3. The Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX)

SAMPEX, the first of NASA's new Small Explorer series was launched in July of 1992 carrying four instruments to measure the nuclear composition and electrons in anomalous and galactic cosmic rays, in solar and interplanetary particle events, and in the Earth's magnetosphere. Included are two Caltech/GSFC instruments: a Mass Spectrometer Telescope (MAST); and a Proton Electron Telescope (PET).

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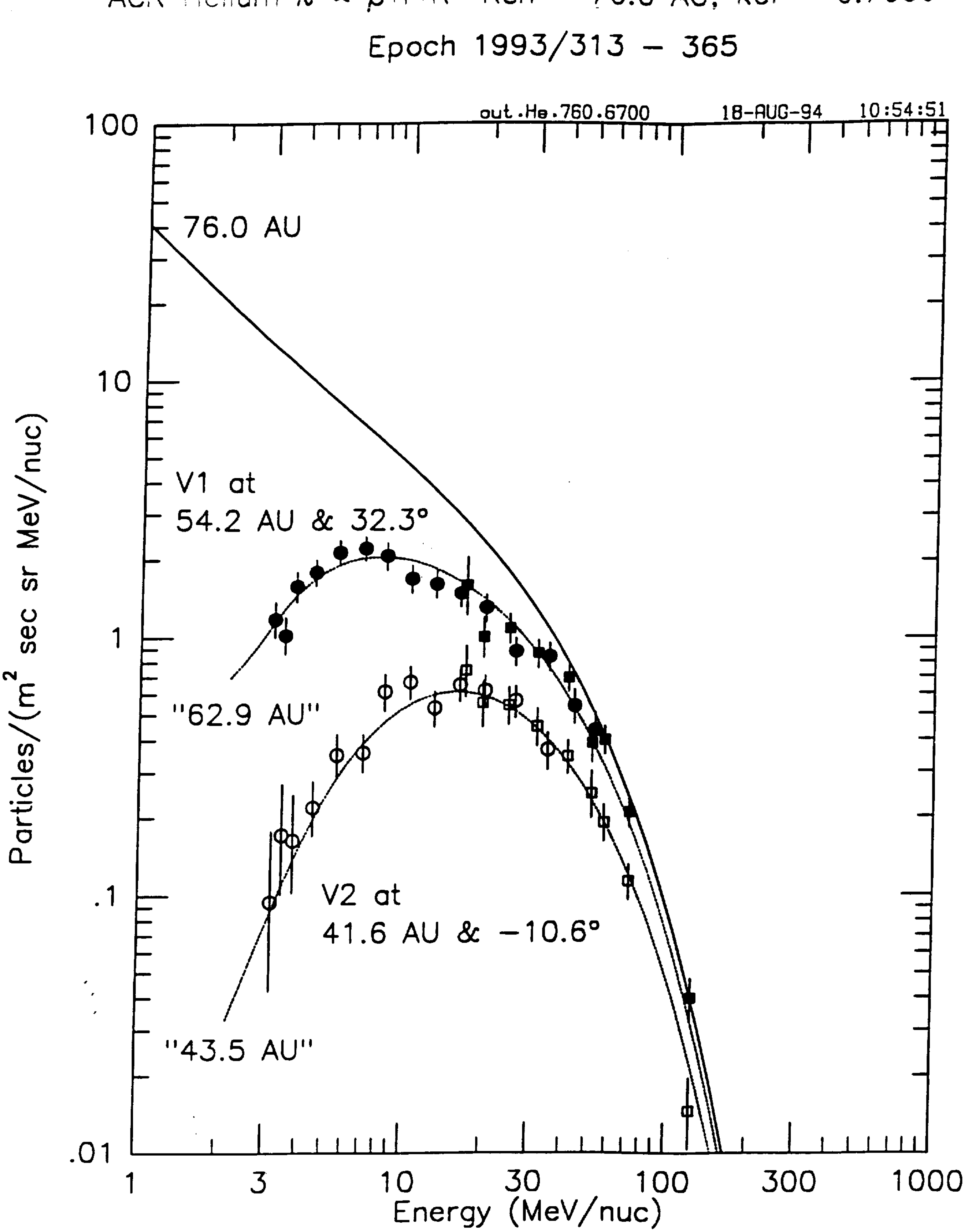

Figure 2.4-1: Anomalous cosmic ray helium spectra from Voyager are fit with a model in which the termination shock is located at ~76 AU.

A primary focus of MAST studies has been a recently discovered radiation belt at L~2 composed of trapped anomalous cosmic rays. An extensive study reporting new measurements of the composition, pitch angle distributions, energy spectra, and time variations of trapped ACRs was recently submitted to JGR.

This past year MAST discovered a radiation belt at L=1.2 that is composed of roughly equal amounts of ^{3}He and ^{4}He (see Figure 2.4-2). The PET sensor has now observed trapped ^{2}H at this same location. This radiation belt apparently results from the nuclear interaction of >100 MeV inner-belt protons with the residual atmosphere, resulting in a host of trapped secondaries.

MAST data are now being used to measure the charge state composition of solar energetic particles at energies of 20 to 30 MeV/nuc, using the Earth's magnetic field as a magnetic filter. A similar approach has been used to measure the energy spectra and composition of anomalous cosmic rays up to energies approaching ~100 MeV/nuc.

MAST data are also being used to study the isotopic composition of solar energetic particles, anomalous cosmic rays, and Galactic cosmic rays. The primary focus of PET data has been in studies of temporal variations of magnetospheric electrons, including the CRRES electron belt formed in April 1991, and precipitating electrons that may influence the chemistry of the upper atmosphere. Work is proceeding on approximately half a dozen SAMPEX papers.

2.4.4. An Advanced Composition Explorer (ACE)

The ACE mission, currently scheduled for launch in 1997, will measure the elemental, isotopic, and ionic charge state composition of energetic nuclei over six decades in energy/nuc, from solar wind to Galactic cosmic ray energies. ACE includes six high-resolution spectrometers, including two, a Cosmic ray Isotope Spectrometer (CRIS) and a Solar Isotope Spectrometer (SIS), for which Caltech has primary responsibility, in collaboration with GSFC, JPL and Washington University. Caltech is also responsible for overall management of the scientific payload (with E. C. Stone the Principal Investigator for ACE), and it will be the home of the ACE Science Center.

The ACE instruments are now well into Phase C/D development, leading to delivery of the instruments to the spacecraft in mid-1996. SIS and CRIS successfully completed their Preliminary Design Reviews in April of this year. The principal new technological developments that are being made for SIS and CRIS include: 1) new, large-area solid state detectors; 2) custom, low-power VLSI circuitry; and 3) a Scintillating Optical Fiber Trajectory (SOFT) hodoscope for CRIS that is being developed by Washington University. Critical Design Reviews for SIS and CRIS are scheduled for this coming October.

2.5. Other Activities

R. A. Mewaldt is serving as Chairman of the Cosmic Ray Program Working Group, as a member of the Cosmic and Heliospheric Management Operations Working Group (CHMOWG), and as a member of the NAS/NRC Panel on Cosmic Rays. T. L. Garrard is Discipline Coordinator for the Space Physics Data System. A. C. Cummings served as a member of CHMOWG and the Heliospheric Program Working Group, as a member of the Pluto Fast Flyby Science Definition Team, and a member ofthe Cosmic and Heliospheric Discipline Coordination Team of the NASA Space Physics Data System.

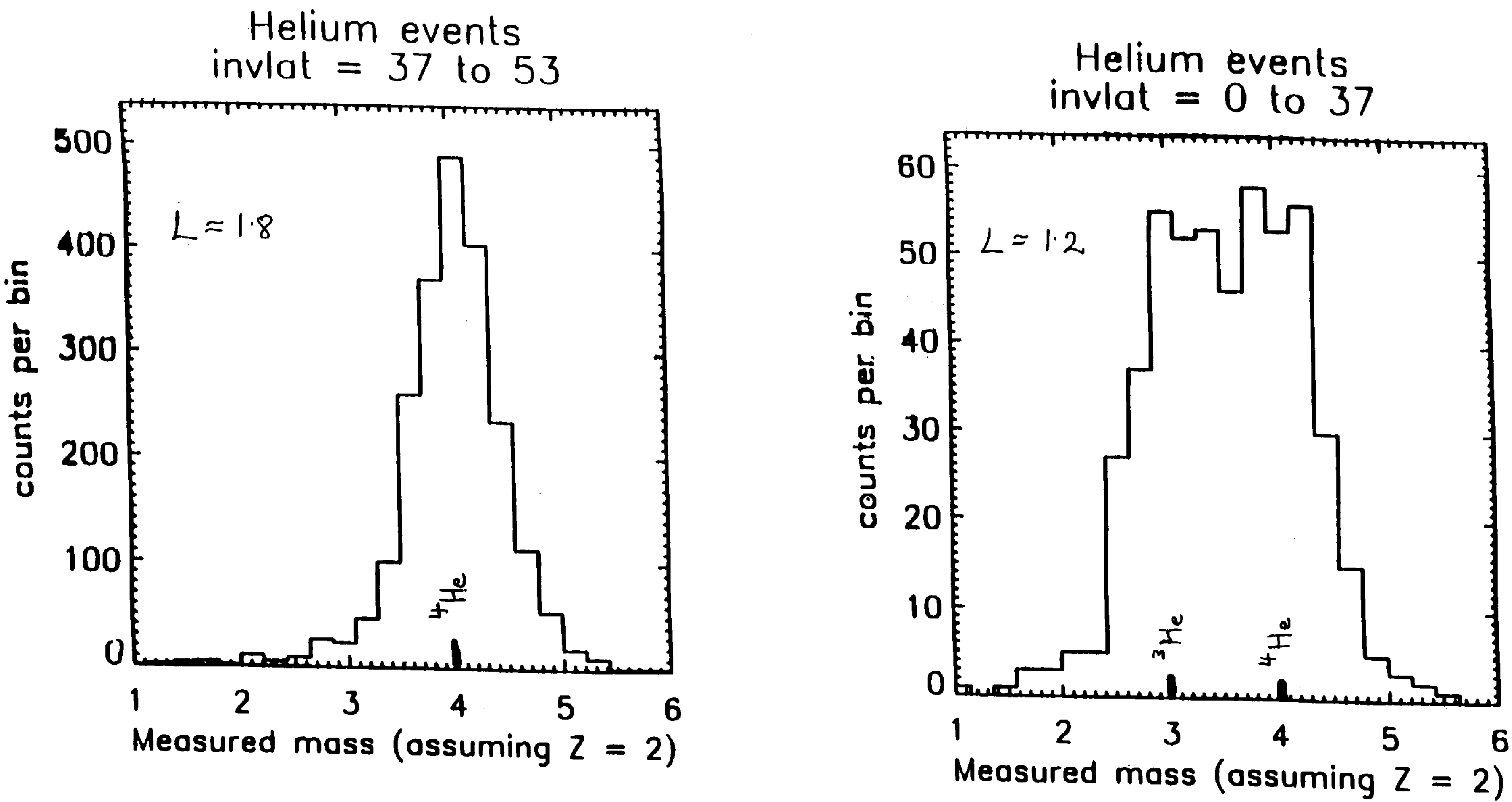

Figure 2.4-2: Mass histograms of He isotopes from two locations in the magnetosphere, L=1.2, and L=1.8.

3. BUDGET

A cost plan for our FY1995 activities is attached.

4. BIBLIOGRAPHY

A bibliography of SRL papers for the past year is attached.

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